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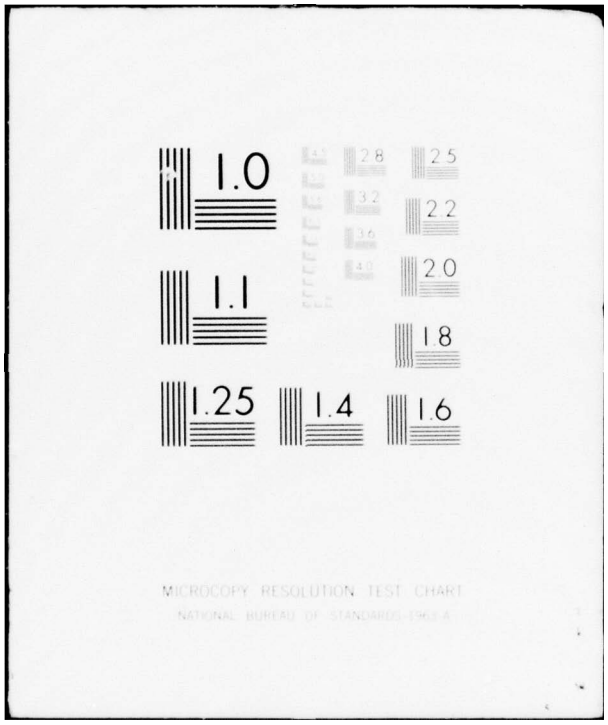
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OPERATIONS RESEARCH CENTER

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

ANNUAL REPORT

July 1, 1975 through June 30, 1976

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(11) 30 Jun 76

(12) 54p.

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I. INTRODUCTION

The Operations Research Center conducts interdepartmental academic and research programs in operations research. The academic staff of the Center is drawn from many departments, including Sloan School of Management, Urban Studies and Planning, Electrical Engineering and Computer Science, Aeronautics and Astronautics, Mathematics and Physics. At present, approximately 15 students are in the operations research doctoral program and a comparable number are in the master's program. Most of them come to M.I.T. specifically to study operations research and are admitted directly by the Center, although some learn about the graduate operations research programs by attending seminars or courses.

During the past year, the academic staff of the Center have engaged in a wide range of research activities sponsored directly by the Center. There was basic research into the methodologies underlying operations research including mathematical programming, decision analysis, and probabilistic models. There was also a variety of model building and applications-oriented research using these methodologies.

Basic research into the mathematics of operations research received continued strong attention. This year's developments included further work on the use of mathematical programming duality theory to study integer programming. New results were obtained on sensitivity analysis and multi-criterion optimization of these problems. Research was performed on the solution of nondifferentiable optimization problems, a class which includes the above mentioned integer programming dual problems. Additional significant research was performed in robust statistics, network optimization and fractional programming.

An important research project which began last year was joint research with The Center for Transportation Studies into decomposition techniques. Three application areas were considered and analyzed: freight flow management, multi-fleet routing, and urban goods distribution. The research involved model building, mathematical programming analysis, and computer implementation and validation. Decomposition methods are required because of the large size of these decision problems.

Another applications project was concerned with public attitudes and decision processes regarding blood donation. The field work for this project, including survey research in seven metropolitan areas, was completed this year. Several aspects of the study, such as investigations of samples of ex-donors, cast doubt on the popular belief that the reluctance of the public to donate is the primary constraint on blood supply.

Substantial progress was made last year in a long standing project devoted to the study of multilevel logistics systems. Research was

completed on methods to partition, link, aggregate and disaggregate large scale production, distribution and inventory systems. In addition, computer programs were implemented and tested for the solution of mathematical programming that can be used to support production planning decisions.

Operations Research Center staff and students were involved in a variety of research activities with other departments and centers both within and outside M.I.T. For example, several students and staff were involved in joint work with the M.I.T. Energy Laboratory. A network flow model was designed and implemented to predict local shortages of heating oil in emergencies and to determine fuel inventory management. Research continued on a probabilistic model of the oil and gas process that constitutes the physical component of an economic supply function for petroleum reserves from new discoveries. Computational methods were developed for estimating parameters of the model and forecasting sizes of new discoveries and these methods were applied to the North Sea petroleum exploration sites. Finally, there was research into an important class of economic equilibrium/mathematical programming used in energy planning. Specifically, methods were devised for decomposing these models into their econometric forecasting and linear programming components.

Staff and students participated in a water resources planning project being carried out by the Department of Civil Engineering. This project is concerned with development of the Vardar River Basin in Yugoslavia. A mixed integer programming investment model was constructed to analyze the decision alternatives and computer testing and solution of the model will be done during the first part of next year.

Several members of the Operations Research Center staff were active in research programs at the National Bureau of Economic Research Computer Research Center for Economics and Management Science located in Cambridge, Massachusetts. Their activities included development of interactive computer systems for linear and integer programming and methods of robust estimation. The computer tools developed at the Computer Research Center are publicly available and have been used on many applications of the research projects mentioned previously.

Support for the Center's research during the past year has come from the Army Research Office - Durham, the U.S. Department of Transportation, the Public Health Service, the Office of Naval Research, the National Science Foundation and International Business Machines.

Jeremy F. Shapiro
Acting Director

II. RESEARCH ACTIVITIES

1. Mathematical Methods

1.1 Mathematical Programming and Optimal Control

Staff Reports

T.L. MAGNANTI, Nonlinear Programming and the Maximum Principle for Discrete Time Optimal Control Problems, Revue Francaise d'Automatique, Informatique et Recherche Operationnelle, 3, 75-91, October 1975.

Results in non-linear programming are used to prove a generalized version of the maximum principle for fixed-time discrete optimal control problems. Proofs are based upon the implicit function theorem and a theorem of the alternative for systems of linear inequalities over a convex set: they do not, as in the past, require Brouwer's fixed-point theorem.

T.L. MAGNANTI, Some Abstract Pivot Algorithms, (with C. Greene), SIAM Journal on Applied Mathematics, 29, 530-539, November 1975.

Several problems in the theory of combinatorial geometries (or matroids) are solved by means of algorithms which involve the notion of "abstract pivots." The main example is the Edmonds-Fulkerson partition theorem, which is applied to prove a number of generalized exchange properties for bases.

T.L. MAGNANTI, Optimization for Sparse Systems, M.I.T. Operations Research Center Technical Report No. 119, November 1975. See also, Sparse Matrix Computations (J.R. Bunch and D.J. Rose, eds.), Academic Press, New York, 1976.

Sparse matrices with special structure arise in almost every application of large scale optimization. In linear programming, these problems usually are solved by pivoting procedures, most notably the simplex method, refined and modified in various ways to exploit structure. More recently, iterative relaxation methods and dual ascent algorithms have been proposed for certain applications. In surveying several algorithms from each of these categories, this paper demonstrates the potential for investigating and applying sparse system techniques in optimization.

R.E. MARSTEN, The Use of the Boxstep Method in Discrete Optimization, Mathematical Programming Study 3, 127-144, 1975.

The Boxstep method is used to maximize Lagrangean functions in the context of a branch-and-bound algorithm for the general discrete optimization problem. Results are presented for three applications: facility location, multi-item production scheduling, and single machine schedul-

ing. The performance of the Boxstep method is contrasted with that of the subgradient optimization method.

R.E. MARSTEN, Parametric Integer Programming: The Right-Hand-Side Case, (with T.L. Morin), M.I.T. Operations Research Center Working Paper OR 050-76, March 1976.

A family of integer programs is considered whose right-hand-sides lie on a given line segment L. This family is called a parametric integer program (PIP). Solving a (PIP) means finding an optimal solution for every program in the family. It is shown how a simple generalization of the conventional branch-and-bound approach to integer programming makes it possible to solve such a (PIP). The usual bounding test is extended from a comparison of two point values to a comparison of two functions defined on the line segment L. The method is illustrated on a small example and computational results for some larger problems are reported.

R.E. MARSTEN, A Hybrid Approach to Discrete Mathematical Programming, (with T.L. Morin), M.I.T. Operations Research Center Working Paper OR 051-76, March 1976.

The dynamic programming and branch-and-bound approaches are combined to produce a hybrid algorithm for separable discrete mathematical programs. The hybrid algorithm uses linear programming in a novel way to compute bounds and is readily extended to solve a family of parametric integer programs with related right-hand-sides. Computational experience is reported on a number of linear and nonlinear integer programs.

J.F. SHAPIRO, Using Duality to Solve Discrete Optimization Problems: Theory and Computational Experience, (with M.L. Fisher and W.D. Northup), Mathematical Programming Special Studies 3: Nondifferentiable Optimization, 56-94, November 1975.

Meaningful dual problems have recently been identified for the integer programming problem, the resource constrained network scheduling problem and the traveling salesman problem. In this paper, a general class of discrete optimization problem is given for which dual problems of this type may be derived. The use of dual problems for obtaining strong bounds, feasible solutions, and for guiding the search in enumeration schemes for this class of problems are discussed. Properties of dual problems and three algorithms are discussed, a primal-dual ascent algorithm, a simplicial approximation algorithm and an algorithm based on the relaxation method for solving systems of inequalities. Finally, computational experience is given for integer programming and resource constrained network scheduling dual problems.

RESEARCH ACTIVITIES: Mathematical Methods

J.F. SHAPIRO, Steepest Ascent Decomposition Methods for Mathematical Programming/Economic Equilibrium Energy Planning Models, M.I.T. Operations Research Center Working Paper OR 046-76, February 1976.

A number of energy planning models have been proposed for combining econometric submodels which forecast the supply and demand for energy commodities with a linear programming submodel which optimizes the processing and transportation of these commodities. It is shown how convex analysis can be used to decompose these planning models into their econometric and linear programming components. Steepest ascent methods are given for optimizing the decomposition, or equivalently, for computing econometric equilibria for the planning models.

J.F. SHAPIRO, Sensitivity Analysis in Integer Programming, M.I.T. Operations Research Center Working Paper OR 048-76, February 1976.

A major reason for the widespread use of LP models is the existence of simple procedures for performing sensitivity analyses. These procedures rely heavily on LP duality theory and the interpretation it provides of the simplex method. Recent research has provided a finitely convergent IP duality theory which can be used to derive similar procedures for IP sensitivity analyses. The IP duality theory is a constructive method for generating a sequence of increasingly strong dual problems to a given IP problem terminating with a dual producing an optimal solution to the given IP problem. Preliminary computational experience with the IP dual methods has been promising. From a practical point of view, however, it may not be possible when trying to solve a given IP problem to pursue the constructive procedure as far as the IP dual problem which solves the given problem. The practical solution to this difficulty is to imbed the use of IP duality theory in a branch and bound approach.

J.F. SHAPIRO, Multiple Criteria Public Investment Decision Making by Mixed Integer Programming, in Multiple Criteria Decision Making, edited by H. Thiriez and S. Zionts, Springer-Verlag, 1976.

A number of public investment decision problems have been formulated as multi-criterion mixed integer programming problems. This paper discusses briefly the specific models which have been proposed. It focuses mainly on mathematical and algorithmic results for analyzing the models.

J.F. SHAPIRO, A Survey of Applications of Integer and Combinatorial Programming in Logistics, in Modern Trends in Logistics Research, edited by W.H. Marlow, M.I.T. Press, 1976.

This survey addresses several specific applications including multi-item production/inventory control problems, warehouse location, natural

gas pipeline design and vehicle scheduling. The use on these problems of generalized programming, Lagrangean techniques, mixed-integer programming and heuristics is discussed.

Student Reports

H.Z. AASHTIANI, Solving Large Scale Network Optimization Problems By the Out-of-Kilter Method, SM in OR Thesis, February 1976.

Recently, data manipulation in the form of basis factorization for linear programs and list processing for networks has been shown to be an important factor in large scale optimization. Much of this effort has suggested that simplex based methods may be superior to primal-dual algorithms for network optimization. In this paper, data structures for primal-dual approaches are investigated, particularly tree saving devices for the out-of-kilter algorithm. Computational results are compared with state-of-the-art running times. Also some sensitivity analysis is reported.

A.A. ASSAD, Multicommodity Network Flows - A Survey, M.I.T. Operations Research Center Working Paper OR 045-75, December 1975. See also, Solution Techniques for the Multicommodity Flow Problem, SM in OR Thesis, June 1976.

This report aims at a comprehensive survey of the literature dealing with the multi-commodity flow problem. This problem arises naturally in network modelling wherever commodities, vehicles, or messages are to be shipped or transmitted from certain nodes of an underlying network to some others. Recent applications of mathematical programming techniques to traffic equilibrium problems in transportation studies as well as computer networks analysis has renewed considerable interest in this problem.

This report discusses solution techniques for both linear and non-linear flow problems. The former include decomposition, partitioning, compact inverse methods, and primal-dual algorithms. A variety of feasible direction methods for the latter are described. The report concludes by giving applications and computational experience for both types of problems.

B.L. GOLDEN, Shortest Path Algorithms: A Comparison, M.I.T. Operations Research Center Working Paper OR 044-75, October 1975.

This note presents some computational evidence to suggest that a version of Bellman's shortest path algorithm outperforms Treesort-Dijkstra's for a certain class of networks.

B.L. GOLDEN, A Statistical Approach to the TSP, M.I.T. Operations Research Center Working Paper OR 052-76, April 1976.

This paper is an example of the growing interface between statistics and mathematical optimization. A very efficient heuristic algorithm for the combinatorially intractable TSP is presented, from which statistical estimates of the optimal tour length can be derived. Assumptions, along with computational experience and conclusions are discussed.

R.T. WONG, A Survey of Network Design Problems, M.I.T. Operations Research Center Working Paper OR 053-76, May 1976.

This report is a survey of the design of various types of networks that frequently occur in the study of transportation and communication problems. The report contains a general framework which facilitates comparisons between problems. A large number of different network design problems are discussed and computational experience for the various solution techniques are given.

1.2 Decision Analysis, Statistics and Stochastic Systems

Staff Reports

A.I. BARNETT, On Searching for Events of Limited Duration, Operations Research, 24, May-June 1976.

Given a set of events, an observer wishes to detect as many of these as possible. The events arise at several discrete points according to independent Poisson processes, and the lifetimes of individual occurrences are independent and identically distributed random variables. The specific problem is: given that the observer can only visit one point per unit time, in what sequence should he make his visits so as to maximize the steady-state fraction of events he detects? We obtain some results about the optimal search policy and find the best policy precisely in some circumstances.

G.M. KAUFMAN, On Sums of Lognormal Random Variables, M.I.T. Sloan School of Management Working Paper WP 831-76, February 1976.

Approximations to the characteristic function of the lognormal distribution are computed and used to calculate approximations to the density of sums of lognormal random variables.

RESEARCH ACTIVITIES: Mathematical Methods

R.C. LARSON, "The Hypercube Queuing Model: An Introduction to Its Structure and Utility," M.I.T. Innovative Resource Planning Project Technical Report No. 20-75, December 1975.

The hypercube queuing model provides a quantitative framework for spatially redeploying or revising the dispatching procedures of emergency response units (such as those found in municipal police, fire, and ambulance services). The model computes a mixture of performance measures that allows a planner to focus simultaneously on several region-wide objectives while assuring the spatial inequities in the delivery of service are maintained at an acceptable minimum.

This paper presents in a fairly nontechnical manner the underlying motivation for the hypercube model and the basic elements of its structure. After discussing the model in the context of queuing (waiting line) systems, the paper introduces the concepts of state, transition, and equilibrium behavior. These concepts are illustrated within the hypercube framework. System performance measures are computed using the "solution" to the hypercube model.

If the planner wishes only an approximate set of values of performance measures, a computationally efficient approximation procedure is outlined.

P.M. MORSE, The Geometric and the Bradford Distributions, A Comparison, M.I.T. Operations Research Center Working Paper OR 049-76, February 1976.

Both the geometric and the Bradford probability distributions are used to describe collections of items of interest in information science. Each unit item has a productivity, an integer n measuring the amount of use of the item. The cumulative F_n of items with productivity equal to n or greater may be expressed as a function of n or else as a function of the cumulative mean productivity G_n of items with productivity equal to n or greater. If F_n is an exponential function of n, the distribution is geometric; if it is an exponential function of G_n, it is a Bradford distribution. The exact solution of F_n as a function of n for the Bradford distribution is computed; the results are tabulated. Graphs are given, comparing the two distributions, and their relative usefulness is discussed.

R.E. WELSCH, Stepwise Multiple Comparison Procedures, M.I.T. Sloan School Working Paper No. 816-75, 1975.

This paper proposes two new stepwise multiple comparison significance tests which control the experimentwise type I error rate and compares them with some existing procedures. The new (step-up) tests begin by

examining the gaps between adjacent ordered sample means, then the three-stretches, four-stretches, and so on until the range is reached. This reverses a procedure (step-down) proposed by Ryan which also controls the experimentwise error state.

Tables for the new tests were constructed using improved Monte Carlo techniques. The paper also contains tables for a version of the Ryan procedure based on the studentized range. A simulation study showed that one of the new step-up tests and the modified Ryan procedure provided significantly greater power than the commonly used Tukey Honestly Significant Difference test.

R.E. WELSCH, Confidence Regions for Robust Regression, 1975 Proceedings of the ASA Statistical Computing Section, American Statistical Association, Washington, D.C., 1975.

In the past few years, a number of ways have been proposed to perform robust regression. Perhaps the simplest to implement is called iteratively reweighted least-squares. Initial values for the coefficients are found, a scale for the residuals from this start is computed, and then a set of weights is determined by using a weight function applied to the scaled residuals. The weight function usually gives a value near one for small residuals, and near zero (or equal to zero) for large residuals. The weights are then used as if they were the weights for a weighted least-squares (WLS) regression. The above process can, of course, be iterated.

Therefore, all one needs is a device to compute the start, scale, and weights and the rest of the computation (the hard part) can be done with a standard WLS routine or by multiplying each observation by the square root of the corresponding weight and using an LS routine.

Naturally, the question arises - can we use the output from the WLS routine to find confidence regions for the regression parameters? This would make life simpler and make robust regression more readily usable. One purpose of this study of robust regression was to see if it would be feasible to use WLS output in a simple way.

This paper is organized as follows: section two discusses the robust estimator (weight function) used, section three covers the covariance formulas, section four examines the design [X] matrix used, and section five summarizes the parameters and distributions used in the Monte Carlo. In section six, the results for the location case are discussed. The seventh covers work on the regression problem and in the last section, advice is given.

RESEARCH ACTIVITIES: Mathematical Methods

R.E. WELSCH, The Variances of Regression Coefficient Estimates Using Aggregate Data, (with E. Kuh), Econometrica, 44, 353-363, March 1976.

This paper considers the effect of aggregation on the variance of parameter estimates for a linear regression model with random coefficients and an additive error term. Aggregate and micro variances are compared and measures of relative efficiency are introduced. Necessary conditions for efficient aggregation procedures are obtained from the Theil aggregation weights and from measures of synchronization related to the work of Grunfeld and Griliches.

Student Reports

S.E. BODILY, Collective Choice with Multidimensional Consequences, PhD in OR Thesis, February 1976.

This work considers decision problems where alternatives have consequences to each of a collection of individuals or interest groups. It contributes to both the theoretical understanding of collective choice problems and to the development of a methodology for aggregating consequences.

A taxonomy of collective choice formulations provides the context for contrasting a surrogate utility formulation, explored in this work, with other approaches. With x_j^i the consequence to individual i measured by numeraire j, the surrogate utility function (SUF) provides a cardinal ranking of alternatives by aggregating $\{x_j^i,\ i = 1,2,\ldots,n,\ j = 1,2,\ldots,m\}$ into a scalar.

Two aggregate schemes for SUF are studied. 1) Personal preference aggregation (PPA) aggregates first over j for each individual and then over individuals. 2) Numeraire aggregation (NA) aggregates first over i for each numeraire and then over numeraires. Motivation and mathematical forms for the SUF under each aggregation scheme are given. When individual preferences are used to aggregate the elements in each row, we verify that Arrow-like normative conditions can be satisfied. Several models are given for assigning the parameters of the SUF, including a participatory model for achieving consensus. A methodology for direct assessment of preferences is developed and the rationale is presented for making the necessary interpersonal comparisons of consequences.

New theoretical results are obtained for state-dependent utility functions, where consequences to a subgroup of individuals are not utility separable from consequences to others, but rather depend on a state descriptor of others' consequences. The axiomatic bases for several forms of a state-dependent SUF are derived.

RESEARCH ACTIVITIES: Mathematical Methods

Under NA, a normative methodology for ranking interpersonal dispersions to consequences is provided and its advantages relative to traditional ad hoc approaches to measuring inequality is indicated. When distributional judgments are made in conditions of uncertainty, a dilemma arises concerning whether prior or posterior equality (or equity) is desired. A state-dependent SUF is used to resolve the dilemma.

RESEARCH ACTIVITIES

2. Models and Applications

2.1 Urban and Other Public Systems

Staff Reports

A.I. BARNETT, On Urban Homicide: A Statistical Analysis, (with D.J. Kleitman and R.C. Larson), Journal of Criminal Justice, 3, 85-110, 1975.

A statistical analysis is made of homicide rates in the 50 largest American cities for four different years. It is shown that differences in recent murder growth among the cities can largely be explained as typical random fluctuations about a common trend. It is also found that the changing age profile of the American people explains no more than ten percent of the increase in homicide since 1964. Several mathematical models for future homicide growth are proposed from the analysis, and under each the probability of death by murder and corresponding drop in life expectancy are estimated for individuals born now in each of the 50 cities.

R.C. LARSON, Approximating the Performance of Urban Emergency Service Systems, Operations Research, 23, September-October 1975.

This paper presents an approximate procedure for computing selected performance characteristics of an urban emergency service system. Based on a recently developed hypercube queuing model, the procedure requires for N servers solution of only N simultaneous equations, rather than 2^N as in the exact model. The procedure relies on the theory of M/M/N queues in which servers are selected randomly and without replacement until the first available (free) server is found. The underlying model is intended for analyzing problems of vehicle location and response district design in urban emergency services, includes interdistrict as well as intradistrict responses, and allows computation of several point-specific as well as area-specific performance measures.

R.C. LARSON, Dispatching the Units of Emergency Service Systems Using Automatic Vehicle Location: A Computer-Based Markov Hypercube Model, (with E.A. Franck), M.I.T. Innovative Resource Planning Project Technical Report No. 21-76, April 1976.

Automatic vehicle location (AVL) systems present to the dispatcher of emergency response units (e.g., police cars, ambulances) the estimated real time locations of units within his service area. Building on a recently developed "hypercube queuing model," this paper presents a

Markov process model for computing the operating characteristics of the radio-dispatched fleet operating under a policy that dispatches the closest available unit to each call for service (i.e., a perfect resolution AVL system). The model accommodates a realistic description of the service area and rather general spatial deployment policies for units.

In implementing the model for efficient computer execution, the focus is on computation and storage minimizing procedures for generating the state-to-state Markov transition rates. One useful technique involves the effective application of a recently developed backward regenerative unit-step tour of the hypercube. The algorithmic procedures generalize to computer solutions of M/M/N queuing systems with distinguishable servers, different customer classes, and a cost structure for assigning servers (who may be in one of several postures) to customers of each class.

The paper concludes with a realistic nine-unit police example that indicates the general ways in which AVL dispatching improves (and degrades) system performance.

A.R. ODONI, Expenditure and Employment Trends in Large City Police Departments: 1959-1973, M.I.T. Innovative Resource Planning Project Technical Report No. 16-75, July 1975.

This report is concerned with a review of trends in employment and expenditures at major city police departments in the United States for the years 1959 through 1973. The 13 largest police departments, in terms of the number of employees, are grouped together (Group A) and considered in parallel with a group of 20 police departments in medium-size (population 300,000-750,000) cities (Group B).

The report examines in detail a number of points related to police employment and expenditures, including: the size of the growth in city expenditures for the police on an absolute basis and in relation to expenditures for the provision of other services; changes in expenditures for salaries and wages and for the various types of fringe benefits; salary and wage increases for sworn police employees and for supervisory personnel in inflated and in constant prices; and, changes in the size and composition of police work forces.

Several long-term trends become readily apparent as a result of this examination: Over the years of interest, police protection costs have increased at a rate far exceeding the rate of cost increases in most other sectors of private or public activity. On the other hand, the growth rate of police expenditures is not far out of line with the growth rate of expenditures for many other municipal services. Salaries and wages as well as fringe benefits for all categories of police employees have improved dramatically over the years (and especially so

during the 1966-73 time period). Typical present worth costs for the hiring of a new policeman by a large- or medium-size city in 1973 are close to $300,000 (in 1973 prices). Although per capita costs of police protection in Group A cities were considerably larger than in Group B cities, growth trends (as evidenced by the rates of changes in police employment and expenditures) exhibited minimal differences. The composition of police forces has also been changing to some extent, with increased proportions of supervisory personnel and of civilian employees evident at most police departments.

The extent to which all the aforementioned trends will continue at a similar level of intensity is a matter for speculation at this time, due to the major crisis that local government finances seem to be going through.

Student Reports

K.R. CHELST, Quantitative Models for Police Patrol Deployment, PhD in OR Thesis, September 1975.

A primary task of the police administrator is to make the most efficient and effective use of his manpower. In addition, because police provide a public service, an important issue in the deployment of police personnel is that each segment of the community be allocated an equitable share. Models are presented that focus on the spatial component of these deployment goals.

Interactive computer models are formulated to aid a police planner design patrol sectors which represent a good balance among often conflicting objectives (e.g. response times, workloads). The models guide the decision maker iteratively through a series of alternative sector designs while providing him with information about a spectrum of performance measures. An integral part of the system is a set of algorithms that can modify an initial sector design to greatly improve imbalances in either workload, preventive patrol coverage or response time. Computational experience is presented.

A second set of models is presented which focuses on the more effective deployment of randomly patrolling police units as measured by the probability of intercepting a crime in progress. The discussion begins with a presentation of a basic search theoretic model of police patrol which is used to calculate the probability of intercepting a crime. As part of the analysis of the model's input parameters, the critical need for a police patrol related data base is discussed and some of its salient features (e.g. duration and observability of various crime types) are outlined. Then, using the model, the differences between overlapping and non-overlapping patrol sectors are explored.

RESEARCH ACTIVITIES: Models and Applications

The development of methodologies for deploying patrol units proceeds in several stages. First, the impact on the classical search theory allocation problem of various characteristics of crimes (e.g., random arrival, short duration, multiple independent targets) is analyzed. A continuous time differential equation model of search and detection provides the vehicle for carrying out much of this analysis. Optimal solutions for a number of classical search problems are presented including simple closed form expressions for determining if a region should be excluded from the search. The main result of this analysis, however, is the generation of a number of important insights which simplify the development of algorithms for deploying police.

An algorithm for deploying a tactical patrol force (i.e., limited or no responsibility for calls for service) is presented. The measure of effectiveness that is used is the weighted (a user specified index that weights the various crime types) probability of intercepting a crime. An essential component of the algorithm is its ability to perform sensitivity analysis on the various input parameters.

Lastly the development of an algorithm for effectively allocating the patrol time of standard patrol units is outlined. Once again the measure used is the weighted probability of intercepting a crime. The discussion closes with a description of what questions need to be answered before a total model of police patrol can be developed.

D.W.J. CHIN, An Evaluation of Indices for Predicting Medical Service Usage in Nursing Homes, SM in OR Thesis, September 1975.

This thesis deals with the need for finding an index which relates a patient's clinical fragility to the amount of medical services that he can be expected to receive. It begins by describing the background of the Nursing Home Telemedicine (NHTM) experiment at the Boston City Hospital. It introduces the concept of classifying patients according to their medical needs and to their nursing needs. The potential uses of the clinical fragility index as both a research and administrative tool are described. The general importance of the clinical fragility index and its relevance to the evaluation of the NHTM experiment are discussed.

The procedures of the data analysis for evaluating alternative clinical fragility indices are presented. Procedures are also presented for the evaluation of the NHTM experiment which explicitly take clinical fragility into account.

In the absence of the completed final data set for the NHTM experiment at the time of this writing, a limited analysis has been done on a small group of telemedicine patients to produce some preliminary results. These results indicate that it is possible to develop a clinical fragility index and further research is merited.

RESEARCH ACTIVITIES: Models and Applications

E.A. FRANCK, Implementing Closest Vehicle Dispatching Strategy on the Hypercube Model, SM in OR Thesis, February 1976.

In urban emergency service systems (e.g., police, fire, and ambulance services), increased attention is being focused on various technological innovations for improving operational performance.

Automatic vehicle location (AVL) systems comprise one important class of such innovations. These systems would present to the radio dispatcher the estimated locations of all emergency response units under his jurisdiction. Dispatch decisions could then be made with an awareness of these estimated locations, resulting in improved operations compared to standard manual dispatching procedures.

This paper presents a method for modeling analytically one simple form of dispatching using AVL information. It is assumed that the exact, real-time locations of all response units are known (i.e., a perfect resolution AVL system) and that the dispatcher always dispatches the closest available response unit to an incident (closest vehicle dispatching).

The model builds on "the hypercube queuing model", which is a spatially distributed queuing model developed recently to analyze analytically the performance of urban emergency services. Various algorithms and theoretical concepts of the hypercube model are extended to incorporate in an efficient manner the more complicated dispatching mechanism presented by the AVL system.

The hypercube implementation of the closest available vehicle strategy computes all of the standard hypercube performance measures: workloads of each of the units, mean travel times and cross-area dispatch frequencies. In addition, it computes the point specific dispatch error probabilities for any of the current manual strategies, the mean travel time reductions and the variations in intersector dispatch frequencies.

The new model is applied to two different regions, the first of which was studied earlier with a simulation model. Results for that region are shown to be very similar to those obtained by simulation, however, at a much smaller cost. Moreover, the point-specific performance measures were not calculated by simulation, being too expensive, and are thus available for the first time.

J.H. JOHNS, Intelligent Computer-Aided Dispatching for Urban Police Patrol Units, SM in OR Thesis, September 1975.

Current computer-aided dispatch (CAD) systems for urban police do not utilize the full potential of the computer and associated peripheral equipment in the processing of calls for police service. This report

proposes ways in which CAD systems can be used more efficiently in the dispatching process.

The capabilities of a typical operational computer-aided dispatch system are examined, and problem areas in the dispatching process are identified. Results of a survey of a small group of urban police departments are included which indicate additional problems in the dispatching of patrol units and opinions of police administrators regarding facets of police patrol operations which can benefit from the more complete utilization of computer capabilities.

Several "intelligent" computer-aided dispatch algorithms are presented which improve the dispatching process by taking advantage of the computational, storage, and rapid printing capabilities of computers and peripheral equipment. A specific CAD algorithm termed "adaptive dispatching", a strategy for the stacking of low priority calls for service which uses information concerning the length of the present period of service of each patrol unit, is examined in detail through simulation techniques. This strategy is shown to be an effective means for significantly decreasing the number of intersector dispatches with acceptable increases in average waiting times of calls for police service.

Important factors for ensuring the success of computer-aided dispatch systems are identified, along with policies for the implementation of systems of advanced technology and operational impacts of such systems on departmental procedures and personnel. Areas for further research in CAD technology are outlined.

G. LAURENT, A Dynamic Analysis of the Housing Market in Paris, SM in OR Thesis, June 1976.

This thesis has a practical motivation (to analyze the mechanisms under the fluctuations that plague the market for new housing in Paris) and a methodological motivation (to show how a behavioral model, an econometric estimation, a System Dynamics model can reinforce each other in a study).

For each of three key variables (apartment sales; apartments placed for sale on the market; increase in apartments selling price), a behavioral model was derived from interviews, then supported (and, on one point, modified) by an econometric estimation.

The number of apartments placed on the market is described as depending on the sales and unsold inventory observed on the market in the recent past. Sales of apartments are described as depending on the monthly installment that a buyer must pay to reimburse the loan contracted to buy the apartment (this installment depends on credit, and apart-

ment price), compared to the buyer's income; sales also depend on population size. The increases in apartment price are described as depending on construction cost, as well as on recent sales.

The results of the econometric estimation were put in the form of a System Dynamics simulation model. This model showed "performance characteristics" similar to those observed in the real market, and this supported our previous belief in the model.

A simplified System Dynamics simulation model was then used to assess what would be, according to our model, the answer of "promoteurs" (the agents who build apartments) to some hypothetical sales pattern. We assert that the behavior of promoteurs would tend to prolongate the effect of external "pulse" disturbances for a few years after they happened; and, in addition, to transform random external disturbances into apparent fluctuations.

After a comparison with other econometric studies of the housing market, the model of the promoteurs' behavior is formulated in more general terms, in the form of a model which should hold true of many markets. It is suggested that the current market for office space in New York may be another case example of this more general model.

J.A.Y. LIM, The Effects of Socio-Eco-Demographic Factors and Family Planning Programs on Fertility, SM in OR Thesis, February 1976.

The controversial disagreement between the Third World and the developed countries as exhibited in the World Population Conference of 1974 in Bucharest focused on whether population control is best achieved through concentration on socio-eco development or on intensive family planning programs.

This study tries to discover the effects of socio-eco conditions as well as some crude family planning measures on fertility through factor and regression analyses on data from Third World countries. These methods, however, can only ascertain the existence and magnitudes of correlative relationships and cannot imply causal effects.

The analysis indicated that socio-eco-demographic conditions do have very strong and statistically significant relationships with fertility. Futhermore, family planning program measures also seem to have significantly strong correlation with economic growth, education and population density.

Family planning measures fail to show significant relations with fertility. This is most probably due to the crudeness of data used in this study as well as the lack of sophistication and experience in family planning of most Third World countries.

This supports the case for the importance of socio-eco conditions in population control. However, the lag between development and fertility must be determined before development can be recommended as a solution to the population problem.

It is safe to suggest that both developmental and family programs be adopted. Further studies - preferably at the micro level - need be made to determine the amount of concentration on each. But family planning programs should be considered in conjunction with the socio-eco-demographic situation.

L.J. OSWALD, III, Preemption - A Viable Strategy?, SM in OR Thesis, September 1975.

This report develops a structure that may be used to define, evaluate, and eventually implement a preemptive dispatching strategy for the police.

It is assumed that there are two priorities of customers, urgent and nonurgent, and that if prescribed spatial conditions are met, the patrol unit serving the nonurgent customer will be interrupted and dispatched to the urgent caller. The strategy has been defined such that the non-urgent customer will immediately have another server assigned. A spatial model, based on an $M/G/\infty$ service system, is created to define the spatial context of preemption.

The spatial information is integrated into a Decision Analysis of a preemptive dispatching strategy. A decision tree is developed that delineates the dispatching process. Then a Group Multiattribute Utility Function is formed, by nesting two, four-attribute Group Multiattribute Utility Functions of the police and the customer, to evaluate alternative actions. The function includes subjective as well as objective measures. An analysis of a feasible computer program package is presented.

Numerical estimates are used to illustrate the properties of the structure that has been developed to describe preemptive dispatching. The model is seen to be a valuable tool that can be used to analyze and evaluate a preemptive dispatching strategy. It not only provides a means to define the problem, but it also increases the decision maker's understanding of the complex interactions that will occur.

The conclusion will suggest simple data collection and operational procedures that might be used by a police department to initiate "first-step", formal preemptive priority dispatching strategy.

2.2 Traffic and Transportation

Staff Reports

A.I. BARNETT, Control Policies for Transport Systems with Nonlinear Waiting Costs, M.I.T. Sloan School of Management Working Paper No. 850-76, 1976.

The interaction between a transport company and its passengers is modelled as a cooperative game in which the company, subject to an economic constraint, uses the vehicle dispatch strategy under which a time-related cost function for passengers is minimized. A rudimentary transport system is studied in detail, and the joint optimal strategy for passengers and the transport company is obtained.

N. GARTNER, Generalized Combination Method for Area Traffic Control, (with J.D.C. Little), Transportation Research Record, 531, 58-69, 1975.

A simple generalization of the British combination method is given for optimizing offsets in synchronized, traffic-signal networks of a general structure. The method then is used in a recursive procedure to determine values for the offsets along each street, the splits of green time at each intersection of the network, and the common cycle time of the controlled area. The signals' cost to travelers is evaluated as the sum of 2 components: one associated with a deterministic traffic-flow model and the other associated with randomness in traffic behavior. The deterministic component is a function of the coordination among the signals in the network and generally increases with cycle length. The stochastic component depends on the expected overflow queue at each traffic light and decreases with cycle length. It is shown that optimal settings are determined at the equilibrium point of minimum total cost resulting from the combined effect of the 2 components.

N. GARTNER, Optimization of Traffic Signal Settings by Mixed-Integer Linear Programming, Part I: The Network Coordination Problem, (with J.D.C. Little and H. Gabbay), Transportation Science, 9, 321-343, November 1975.

Setting traffic signals as a signal-controlled street network involves the determination of cycle time, splits of green time, and offsets. Part I of this paper considers the network coordination problem, i.e., given a common cycle time and green splits at each intersection, determine offsets for all signals. In Part I, a link performance function is developed to express the loss incurred by platoons traveling through a signal-controlled intersection as a function of link offset. Integer variables enter the formulation because of the periodicity of the traffic lights: The algebraic sum of the offsets around any closed loop

of the network must equal an integral number of cycle times. The optimization problem is formulated as a mixed-integer linear program and a test network is solved by branch-and-bound techniques using IBM's MPSX package.

N. GARTNER, Optimization of Traffic Signal Settings by Mixed-Integer Linear Programming, Part II: The Network Synchronization Problem, (with J.D.C. Little and H. Gabbay), Transportation Science, 9, 344-363, November 1975.

Results obtained in Part I are extended to include offsets, splits at each intersection, and a common cycle time for the network as simultaneous decision variables. In addition to the deterministic link performance function, the stochastic effects of overflow queues from one cycle to the next are modeled by means of a saturation deterrence function that enters as an additive component in the objective function. Computational results demonstrate the feasibility of using mixed-integer linear programming on problems of realistic size. Sensitivity analysis of cycle time shows it to have a strong influence on network performance.

A.R. ODONI, Airport Quotas and Peak Hour Pricing: Theory and Practice, (with J.F. Vittek), Report No. FAA-AVP-77-5, U.S. Department of Transportation, May 1976.

This report examines the leading theoretical studies not only of airport peak-hour pricing but also of the congestion costs associated with airport delays and presents a consistent formulation of both. The report also considers purely administrative measures, such as quotas, and hybrid systems which combine administrative and economic control techniques. These are all compared to the real-world situation and problems of implementation discussed.

The actual experiences of the Port Authority of New York and New Jersey at the three major New York area airports and the British Airports Authority at Heathrow are then presented. Both organizations administer hybrid quota/peak-hour pricing systems in conjunction with their respective air traffic control authorities. Their experience is compared with the theoretical analyses.

A.R. ODONI, A Handbook for the Estimation of Airside Delays at Major Airports (Quick Approximation Method), (with P. Kivestu), Report No. NASA CR-2644, June 1976.

The handbook contains a set of curves that allow estimation of the average number of total daily delay minutes at a major airport under a variety of conditions. Demand profiles at each airport are classified with respect to the number of daily peak periods, the percentage of daily flights during peak periods, and the number of peak period opera-

tions at the airport. When combined with the saturation capacity of the airport, these descriptors provide sufficient information to allow usage of the handbook.

Examples illustrating the use of the handbook are provided, as well as a brief review and description of the technical approach and of the computer package developed for this purpose.

Student Reports

B.L. GOLDEN, Vehicle Routing Problems: Formulations and Heuristic Solution Techniques, M.I.T. Operations Research Center Technical Report No. 113, August 1975.

An essential element of the newspaper logistics system is the allocation and routing of vehicles for the purpose of delivering newspapers on a daily basis. In this paper, various vehicle routing problems are presented. Formulations defining the mathematical models are discussed in conjunction with several widely-used heuristic solution techniques. The focus is on providing a unified framework for these very difficult combinatorial programming problems.

2.3 Industrial and Management Systems

Staff Reports

A.I. BARNETT, More on a Market Share Theorem, Journal of Marketing Research, February 1976.

The Market Share Theorem of Bell, Keeney and Little is extended to some situations where attractiveness ratings of products are not related "linearly" and symmetrically to their market share. Unique expressions for market share are obtained in these contexts under an axiomatic structure with three postulates, one fewer than used in the original theorem.

C. HAEHLING VON LANZENAUER, Developing an Optimal Repair-Replacement Strategy for Pallets, (with D.D. Wright), M.I.T. Operations Research Center Working Paper OR 047-76, February 1976.

The problem of determining when to repair and when to replace failing equipment is a concern of management of productive resources. Inefficient management due to the use of non-optimal repair-replacement policies can have significant financial implications. The purpose of this paper is to describe the problem, analysis and results of a study which is concerned with determining the optimal repair-replacement strategy for an organization managing a large number of wooden pallets.

RESEARCH ACTIVITIES: Models and Applications

A.C. HAX, The Use of Decision Analysis in Capital Investment Problems, (with K.M. Wiig), M.I.T, Operations Research Center Technical Report No. 118, October 1975.

This paper provides a framework for the formulation and analysis of capital investment projects and illustrates the use of this framework in offering recommendations for a decision affecting a major mining company.

The decision situation being formulated and analyzed in this study corresponds to an actual project undertaken by the authors. At every stage of the analysis, the problems encountered in applying a quantitative approach to capital investment decisions which are the responsibility of top executives of the organization are emphasized. These decisions are influenced significantly by uncertainties, and attitudes toward risk, and multiple objectives. Throughout this paper the problems encountered in implementing this approach are considered, particularly with regard to the impact on the methodology used, and the data collected and processed.

A.C. HAX, The Design of Large Scale Logistics Systems: A Survey and an Approach, in Modern Trends in Logistics Research, W.H. Marlow (editor), M.I.T. Press, 1976.

This paper proposes an approach to the design of model based large scale systems to support logistics decision making. First, several frameworks are presented to classify logistics decisions which suggest the essential characteristics a logistics system should possess. Subsequently a critical review is offered of the current methodology and system development in the field of logistics. Finally, an approach is given to facilitate the design and implementation of logistics decision support systems.

A.C. HAX, On the Design of Hierarchical Production Planning Systems, (with G.R. Bitran), M.I.T. Operations Research Center Technical Report No. 121, February 1976.

To provide effective managerial support to the decisions related to the production planning and scheduling processes, it is useful to partition this set of decisions in a hierarchical framework. In the resulting system higher level decisions impose constraints to lower level actions, and lower level decisions provide the necessary feedback to reevaluate higher level actions. The purpose of this paper is to suggest optimum procedures to deal with the resulting subproblems, and to analyze the interaction mechanisms among the different hierarchical levels. Computational results are given.

RESEARCH ACTIVITIES: Models and Applications

A.C. HAX, Economic and Social Evaluation of Capital Investment Decisions - An Application, (with D.I. Candea and U.S. Karmarkar), M.I.T. Operations Research Center Technical Report No. 123, April 1976.

This paper presents the actual implementation of a risk analysis model to a manufacturing venture undertaken by the government of a foreign country. A major engineering and marketing study was conducted in advance, so that the location and size of the venture were determined prior to the risk analysis. The purpose of our study was to evaluate the profitability of the project both from economic and social points of view. If there had been more than one alternative, the same methodology could have been applied to yield comparative measures of performance.

J.D.C. LITTLE, BRANDAID: A Marketing-Mix Model, Part 1: Structure, Operations Research, 23, 628-656, July-August 1975.

Marketing managers make decisions about price, advertising, promotion, and other marketing variables on the basis of factual data, judgments, and assumptions about how the market works. BRANDAID is a flexible, on-line model for assembling these elements to describe the market and evaluate strategies. This paper motivates the model and presents its mathematics. The structure is modular so that individual decision areas can be added or deleted at will. The model is of the aggregate response type, in which decision variables relate closely to specific sales performance measures. The major submodels are advertising, promotion, price, salesmen, and retail distribution. The advertising submodel employs a long-run sales response to advertising function and a linear lag process. Promotional effects are built up from a characteristic time pattern for the type of promotion and a response curve. Salesmen affect sales through a response process structurally similar to that for advertising. Retail distribution variables are intermediaries that the company affects and that in turn affect customer response. Submodel outputs combine multiplicatively. Competition enters in a modular, symmetric way through a matrix of competitive coefficients that determine the source of sales for each brand as it seeks to increase its market position.

J.D.C. LITTLE, BRANDAID: A Marketing-Mix Model, Part 2: Implementation, Calibration, and Case Study, Operations Research, 23, 656-673, July-August 1975.

Model implementation starts with introductory steps that include orienting management, forming a team, selecting and formulating a problem, calibrating the model, and initial use. Then on-going steps take over with firefighting, tracking and diagnosis, updating and evolution, and re-use. Calibration of the model is approached eclectically in stages that include judgment, analysis of historical data, tracking, field measurement, and adaptive control. A three-year case study shows that unexpected events intersperse a planned implementation. The model

serves not only as a means of evaluating strategies in annual planning and day-to-day operations but also as part of a monitoring system that compares model predictions with actual sales to uncover marketing problems and focus managerial attention upon them.

J.D.C. LITTLE, THE ADVISOR PROJECT: Advertising Budgeting for Industrial Products, (with G.L. Lilien), M.I.T. Sloan School of Management Working Paper WP 823-75, November 1975.

Companies selling to industrial and business markets face the problem of determining how much to spend for various elements in the marketing mix. Setting budgets for advertising expenditures is especially difficult.

This paper reviews the results of the ADVISOR project, a multi-company study of current practice in setting advertising budgets for industrial products. The motivation for the study is that, since information about advertising's effect on sales is virtually nonexistent for industrial products, managers should tap the collective wisdom of those currently making advertising budgeting decisions.

Data on products from a number of large industrial companies have been analyzed to determine those product and market characteristics that affect advertising budgets as well as how those budgets are allocated across media. The study has produced new forms of guidelines for industrial product managers, both for setting the overall advertising budget and for dividing it among media. In addition, new insight into the budgeting process is gained by studying the process in two steps: setting an overall marketing budget and determining advertising's percentage of that budget.

J.D.C. LITTLE, Marketing Issues of 'Waste' Grown Aquatic Foods, (with J. Huguenin), M.I.T. Sloan School of Management Working Paper WP 837-76, February 1976.

Are societal wastes all bad? Some of them, including heat from power plants and certain organic wastes, have been demonstrated to be potentially valuable for growing aquatic food organisms. The use of such "wastes" promises the double benefit of a cleaner environment and an increased food supply. Research and development effort can be expected to solve, for at least some production methods, the technical, economic and public health problems that currently exist.

But can foods grown in part with potentially objectionable inputs be successfully marketed? All evidence indicates that regulatory agencies will require much lower health risk for aquaculture foods than "wild" ones and will ensure explicit labeling of potentially controversial inputs. Knowledge about potential consumer reaction to such food products

is scanty and mixed. Some "waste" grown or "waste" containing foods (many water supplies, some farm and aquaculture products) are regularly consumed, but the public has also reacted swiftly against foods incriminated on health grounds (shellfish affected by red tide, cranberries contaminated by pesticide) and has sometimes been polarized by controversies (fluoridation).

Under these circumstances a likely marketing strategy is to concentrate on aquatic organisms that are not directly used for human comsumption but can be used for animal food or processed for their extracts. For sea foods that are eaten directly (fish, shellfish), a promising strategy is to take advantage of the quality control possible in aquacultural products to produce and market premium foods. These can be sold first to the restaurant trade with direct distribution to preserve maximum freshness, and later to consumers. An interesting possibility in between direct and indirect use is as components of processed and prepared seafoods (fish sticks, fish cakes). Separately and simultaneously a public information campaign can stress the merits and societal advantages of waste utilization.

J.D.C. LITTLE, The ADVISOR Project: A Study of Industrial Marketing Budgets, (with G.L. Lilien), Sloan Management Review, 17, 17-31, Spring 1976.

Companies that sell to industrial and business markets must determine how much to spend for various elements in the marketing mix. No systematic quantitative guidance is currently available to aid managers facing these decisions. ADVISOR, a joint project of M.I.T. and the Association of National Advertisers, addresses this need in the case of advertising budgets. Data on sixty-six diversified products from twelve companies have been analyzed to determine key product and market factors that affect advertising expenditures and media allocation decisions. New forms of guidelines have been developed to aid industrial product managers in setting and allocating advertising budgets by providing information on industry norms, using as input about a half dozen standard product-market factors.

Student Reports

H. GABBAY, A Hierarchical Approach to Production Planning, PhD in OR Thesis, February 1976. See also M.I.T. Operations Research Center Technical Report No. 120, December 1975.

This discussion is begun with an analysis of the hierarchical framework discussed in Hax and Meal, 1975. After defining the different levels of the hierarchy, necessary and sufficient conditions are provided to insure consistency between aggregate and detailed models. Several interpretations and consequences of these results are discussed. In addition,

it is shown that planning horizons to insure consistency on a detailed level are intimately related to planning on an aggregate level. Although the optimality of the approach of Hax and Meal is not demonstrated, lower bounds are easily derived.

For the reminder of the paper, the aggregate product structure of Hax and Meal is not considered. Instead, in a linear model, all items are aggregated together. Under a quite general cost structure, the optimal aggregate production which can be optimally disaggregated is characterized. The analysis is extended from the single to the multi echelon case. Some of the preceding notions are formalized and a more general underlying theory is presented. The aggregate characterization is closely related to properties of Leontief systems. In addition, a new characterization of Leontief Substitution Systems is presented. Finally, the original problem is extended to include both regular and overtime considerations and then fixed charges in production.

U.S. KARMARKAR, Multilocation Distribution Systems, M.I.T. Operations Research Center Technical Report No. 117, September 1975.

A "Multilocation Distribution System" is a system for the distribution of goods that may be held at more than one location in the system. This paper is concerned with the shipping and stocking decisions made in such a system at the short term planning level, involving setting of stock targets and service levels, positioning of stock, and making cost versus service level tradeoffs when the demands to be met are stochastic.

The problem and its important characteristics are described and a framework for identifying problems is developed. The literature, both methodological and applied, is reviewed and discussed critically. The major approaches and their merits and shortcomings are described, and it is asserted that there is a close connection between the stochastic distribution problem and the literature in stochastic programming. This assertion is borne out by examining a simple but general type of distribution problem using programming techniques and showing that it yields convincingly to the treatment.

Next a general convex/stochastic programming problem motivated by the distribution problem is studied and some qualitative characteristics and properties of the problem are described. In particular the form of the optimal policy and optimal cost function are characterized. The results are specialized to the one-period distribution problem and then applied to the multiperiod and infinite horizon problems to show that the same form of policy and cost functions obtains. Some computational methods for the problem are briefly discussed.

Finally, the approach developed here is discussed in the context of distribution system management. It is suggested that it is useful at the

"current" planning level as part of a hierarchical scheme of control. Such a scheme is briefly outlined with a discussion of the factors relevant to the design of an operational distribution management system.

M. MATSUSHITA, An Application of Benders Decomposition to Steel Production, SM in OR Thesis, February 1976.

This paper presents an application to steel production of the Benders Decomposition method for mixed integer programming. A steel company faces many problems which can be modelled as mixed integer programs, but the usefullness of these models has been limited by the difficulty of obtaining optimal, or ever near optimal, solutions. The Benders Decomposition method, devised by J.F. Benders, has been put forward as a way of overcoming this difficulty. This method has been implemented and applied to one of the important mixed integer problems arising in steel production. The overall model consists of a ship scheduling model and several raw materials mixture models for the sintering plants and blast furnaces. A near optimal solution was found after a small number of iterations of the method and in a quite reasonable amount of computer time.

2.4 Energy

Staff Reports

G.M. KAUFMAN, Probabilistic Modelling of Oil and Gas Discovery, (with E. Barouch), proceedings of conference on Energy: Mathematics and Models, July 1975.

The recent availability of a variety of oil and gas reserve forecasts for the U.S. has not contributed to increased confidence as to the empirical nature of the long-run reserve supply function. These estimates are characterized by a high degree of variability.

Perhaps the most striking feature of published forecasts of undiscovered oil and gas is their range. Differences in the amount and quality of geological information employed and in its interpretation, differences in the economic and technical scenarios implicitly or explicitly assumed, and differences in the methods employed for computing forecasts account in part for this enormous range. Few authors discuss in detail how their forecasts can be used in analysis of the relative merits of policy alternatives, even though the end use of a forecast should shape its form.

What is needed, in short, is an analytical approach to this part of the supply estimation problem in which (1) the output is in a form useful for policy analysis, usually the construction of an economy supply function; (2) the model is scientifically credible; (3) the measures of

uncertainty of estimates and of model parameters can be computed; and (4) expert judgment can be explicitly incorporated as personal (subjective) probabilities and blended in a logical fashion with objective evidence as the latter accrues.

J.F. SHAPIRO, OR Models for Energy Planning, Computers and Operations Research, 2, pp. 145-152, December 1975.

This paper discusses how OR models and methods have been used, or could be used, to aid in energy planning. The three specific areas discussed are energy system equilibrium analyses, energy R & D planning models, and models for stockpiling petroleum and allocating it in emergencies. A number of open methodological and model building research questions are presented.

Student Reports

J.A. BLOOM, A Mathematical Model of Fuel Distribution in New England, SM in OR Thesis, February 1976. See also, M.I.T. Operations Research Center Technical Report No. 126, May 1976.

The oil embargo of the winter of 1973-1974 prompted the federal government to impose a mandatory fuel allocation program in order to meet the threat of fuel shortage. The mathematical model developed in this report is designed for use with the allocation program, and its primary purpose is to predict local shortages of heating oil in the short-term.

The model represents the fuel distribution system in New England as a network of nodes connected by flows of fuel. The nodes represent end-users, retailers, large terminals, and offshore source points. The sizes of the flows between the nodes are fixed by the allocation rules, based upon their historical sizes. The distribution model used this data to distribute an estimate of fuel supply from offshore sources among the end-users. An independent model determines end-user demand, which is compared to the supply estimate to determine the size of the shortage.

A detailed model of fuel inventory management is developed. This model assumes that terminal operators manage their inventories in such a way as to minimize the effects of the shortage. The model is formulated as an optimization problem with several alternative objective functions. Using actual data, these objective functions are used to predict the inventory behavior of several terminals during the winter of 1973-1974, and the predictions are compared to the observed behavior in order to determine which objective function most closely models the actual behavior.

RESEARCH ACTIVITIES: Models and Applications

R.E. BROOKS, Allocation of Natural Gas in Times of Shortage: A Mathematical Programming Model of the Production, Transmission, and Demand for Natural Gas Under Federal Power Commission Regulation, PhD in OR Thesis, September 1975.

The purpose of this study was to develop a model of the production, transmission and demand for natural gas which would represent the effects of Federal Power Commission regulation in a realistic manner and which could be used as a tool for analysis of alternative FPC policies regarding producers, interstate pipelines, and the allocation of natural gas in times of shortage. This thesis describes the development of GASNET, a mathematical programming model of the U.S. natural gas system, from its theoretical formulation to its implementation on the SESAME mathematical programming system to forecasts of supply and demand for natural gas in 1980. It also describes the development of a modified linearization algorithm which is shown to converge to a Kuhn-Tucker point of the non-convex, non-linear program which represents the natural gas system under FPC regulation.

RESEARCH ACTIVITIES

3. Computation

Staff Reports

P.P.S. CHEN, The Entity-Relationship Model - Toward a Unified View of Data, proceedings of the Conference on Very Large Data Bases, September 1975.

A data model, called the entity-relationship model is proposed. This model incorporates some of the important semantic information about the real world. A special diagrammatic technique is introduced as a tool for database design. An example of database design and description using the model and the diagrammic technique is given. Some implications for data integrity, information retrieval, and data manipulation are discussed.

The entity-relationship model can be used as a basis for unification of different views of data: the network model, the relational model, and the entity set model. Semantic ambiguities in these models are analyzed. Possible ways to derive their views of data from the entity-relationship model are presented.

A.C. HAX, Computer Programs for Mathematical Programming Models in Production Planning (with S. Pariente), M.I.T. Operations Research Center Technical Report No. 124, May 1976.

Production is concerned with the determination of production inventory and work force levels to meet fluctuating demand requirements. Mathematical programming is suited particularly well for supporting these types of decisions. The first purpose of this paper is to review the different types of mathematical programming models that can be used to support production planning decisions. The second objective is to describe a set of computer programs that allow the input of model data and the solution of the mathematical programming model. Some computational results are also given.

A.C. HAX, COMS: A Computer-Based Operations Management System, (with J. Golovin, M. Bosyj and T. Victor), M.I.T. Operations Research Center Technical Report No. 125, June 1976.

This paper provides a detailed documentation, by means of flow-charts of a computer based production planning and inventory control system. The system relies on the concept of hierarchization of decisions with linkage mechanisms between decision levels. The system has been implemented in L.I.S.P.

T.L. MAGNANTI, Implementing Primal-Dual Network Flow Algorithms, (with H.A. Aashtiani), M.I.T. Operations Research Center Working Paper OR 055-76, June 1976.

This paper shows how data structures similar to those proposed recently for implementing primal simplex based codes for solving network flow problems can be used to implement primal-dual algorithms, particularly the out-of-kilter algorithm. Also studied are several variants of a basic implementation which incorporate options for labeling, for making cost changes, for sequencing the selection of out-of-kilter arcs, and for implementing the primal-dual algorithm. The investigations indicate that storing and manipulating data efficient leads to substantial reductions in computation time as well as storage requirements.

III. EDUCATIONAL ACTIVITIES

A. Subjects Offered by Operations Research Center Staff 1975-76

Subject Number	Subject Title	Instructor	Term	Enrollment
1.11J (2.19J) (16.811J)	Introduction to Systems Analysis	R.L. deNeufville D.H. Marks T.B. Sheridan P. Griffith	Spring	19
1.143	Mathematical Optimization Techniques	D.H. Marks	Fall	56
1.146J (2.192J) (13.62J)	Engineering Systems Analysis	R.L. deNeufville D.H. Marks J.W. Devanney T.B. Sheridan R.E. Stickney	Fall	28
6.041	Probabilistic Systems Analysis	A.W. Drake	Summer	38
6.041	Probabilistic Systems Analysis	A.W. Drake	Fall	161
6.041	Probabilistic Systems Analysis	A.W. Drake	Spring	206
6.251J (15.084J)	Mathematical Programming and Discrete Time Optimal Control	S.K. Mitter T.L. Magnanti	Fall	19
11.521	Social Service Systems	D. Schon J. Ferreira T. Willemain	Spring	18
15.061	Mathematics for Management I	R.E. Welsch	Fall	50
15.061	Mathematics for Management I	R.E. Welsch	Spring	42
15.062	Mathematics for Management II	R.E. Marsten	Fall	87

EDUCATIONAL ACTIVITIES: Subjects Offered

Subject Number	Subject Title	Instructor	Term	Enrollment
15.062	Mathematics for Management II	R.E. Marsten	Spring	64
15.063J (18.457J)	Statistics for Model Building	R.E. Welsch H. Chernoff	Spring	19
15.065	Decision Analysis	G.M. Kaufman	Fall	47
15.065	Decision Analysis	S.E. Bodily	Spring	32
15.073J (18.445J)	Introduction to Stochastic Processes	A.I. Barnett	Fall	18
15.073J (18.443J)	Introduction to Stochastic Processes	A. Petkau	Spring	5
15.075	Statistics for Applications	R.E. Welsch	Fall	43
15.081	Mathematical Programming	J.F. Shapiro	Fall	18
15.081	Mathematical Programming	R.E. Marsten	Spring	29
15.083	Combinatorial Optimization	J.F. Shapiro	Spring	13
15.761	Operations Management	A.C. Hax	Fall	74
15.761	Operations Management	W.A. Martin	Spring	69
15.781	Capacity Planning: Production and Distribution Systems	A.C. Hax T.L. Magnanti	Spring	23
15.795	Seminar in Operations Management	A.C. Hax	Spring	3
16.701	Principles of Systematic Policy Analysis	A.R. Odoni	Fall	18
16.713	Probability Theory	A.R. Odoni	Fall	4

EDUCATIONAL ACTIVITIES

B. Operations Research Seminars

The Operations Research Center seminar series provides an opportunity for students and faculty to hear speakers on operations research from inside and outside M.I.T. All seminars are open to the M.I.T. community and the public. They are often general in content and so provide undergraduates and beginning graduate students with a perspective on O.R. activity.

Sal D'Aversa and Silvia Pariente were the Seminar Coordinators for the year.

September 19	Dr. J.K. Reid Computer Science and Systems Division Atomic Energy Research Establishment Harwell, England	Sparse In-Core Linear Programming
October 19	Dr. David E. Bell Lecturer of Operations Research Division of Engineering and Applied Physics Harvard University Cambridge, Massachusetts	Analysis of Objectives for the Condition of a Forest
October 28	Dr. Romesh Saigal Bell Laboratories Holmdel, New Jersey	Accelerating the Convergence of the Fixed Point Algorithm
November 4	Prof. Jerome Rothenberg Department of Economics M.I.T. Cambridge, Massachusetts	An Econometric Model of Urban Housing Markets
November 25	Dr. W.L. Miranker Mathematical Sciences Department I.B.M. New York, New York	High Order Search Methods for Solving an Equation
December 2	Prof. Thomas L. Morin School of Industrial Engineering Purdue University Lafayette, Indiana	A Hybrid Approach to a Class of Capacity Expansion Sequencing Problems

EDUCATIONAL ACTIVITIES: O.R. Seminars

December 9	Prof. Richard C. Larson Departments of Electrical Engineering and Computer Science and Urban Studies and Planning M.I.T. Cambridge, Massachusetts	What Happened to Patrol Operations in Kansas City? An Operations Research Evaluation of the Kansas City Patrol Experiment
January 13	Dr. Nathan Gartner Visiting Scientist Operations Research Center M.I.T. Cambridge, Massachusetts and	Area Traffic Control and Network Equilibrium
	Prof. Joseph Ferreira Department of Urban Studies and Planning M.I.T. Cambridge, Massachusetts	Risk Management
January 16	Dr. Ronald Frank Cambridge Scientific Center I.B.M. Cambridge, Massachusetts	Applications of Operations Research in Business and Industry
January 20	Prof. Thomas L. Magnanti Sloan School of Management M.I.T. Cambridge, Massachusetts and	Topics in Optimization
	Prof. Roy E. Marsten Sloan School of Management M.I.T. Cambridge, Massachusetts	Parametric Integer Programming
January 22	Dr. Klaus Heis President ICON, Inc. Princeton, New Jersey	Applications of Operations Research in Business and Industry
January 27	Prof. Eytan Barouch Visiting Professor Sloan School of Management M.I.T. Cambridge, Massachusetts and	Estimating Undiscovered Oil and Gas
	Professor Arnold I. Barnett Sloan School of Management M.I.T. Cambridge, Massachusetts	The Greatest Story Ever Told

EDUCATIONAL ACTIVITIES: O.R. Seminars

January 29	Dr. Newton Garber David Sarnoff Research Center RCA Princeton, New Jersey	Applications of Operations Research in Business and Industry
February 24	Prof. Jean-Marc Rousseau University of Montreal Montreal, Quebec	The Bus Crew Scheduling Problem
March 9	Prof. Norman Rasmussen Department of Nuclear Engineering M.I.T. Cambridge, Massachusetts	Nuclear Risk Assessment Methodology
March 30	C. Haehling von Lanzenauer Visiting Professor Sloan School of Management M.I.T. Cambridge, Massachusetts	Optimizing Claims Fluctuation Reserves
May 4	Prof. Peter Mevert College of Business Administration University of Minnesota Minneapolis, Minnesota	On Solving Mixed-Integer Planning Models

EDUCATIONAL ACTIVITIES

C. O.R. Theses Completed

Author	Supervisor
H.Z. AASHTIANI, "Solving Large Scale Network Optimization Problems by the Out-of-Kilter Method," SM, February 1976.	T.L. Magnanti
A.A. ASSAD, "Solution Techniques for the Multicommodity Flow Problem,"SM, June 1976.	T.L. Magnanti
J.A. BLOOM, "A Mathematical Model of Fuel Distribution in New England," SM, February 1976.	H.D. Jacoby
S.E. BODILY, "Collective Choice with Multidimensional Consequences," PhD, February 1976	J. Ferreira R.F. Meyer
R.E. BROOKS, "Allocation of Natural Gas in Times of Shortage: A Mathematical Programming Model of the Production, Transmission, and Demand for Natural Gas Under Federal Power Commission Regulation," PhD, September 1975.	T.L. Magnanti
K.R. CHELST, "Quantitative Models for Police Patrol Deployment," PhD, September 1975.	R.C. Larson
D.W.J. CHIN, "An Evaluation of Indices for Predicting Medical Service Usage in Nursing Homes," SM, September 1975.	T.R. Willemain
E.A. FRANCK, "Implementing Closest Vehicle Dispatching Strategy on the Hypercube Model," SM, February 1976.	R.C. Larson
H. GABBAY, "A Hierarchical Approach to Production Planning," PhD, February 1976.	A.C. Hax
J.H. JOHNS, "Intelligent Computer-Aided Dispatching for Urban Police Patrol Units," SM, September 1975.	R.C. Larson
G. LAURENT, "A Dynamic Analysis of the Housing Market in Paris," SM, June 1976.	G.L. Urban
J.A.Y. LIM, "The Effects of Socio-Eco-Demographic Factors and Family Planning Programs on Fertility," SM, February 1976.	G.L. Urban

EDUCATIONAL ACTIVITIES: O.R. Theses

Author	Supervisor
M. MATSUSHITA, "An Application of Benders Decomposition to Steel Production, SM, February 1976.	R.E. Marsten
L.J. OSWALD, "Preemption - A Viable Strategy?," SM, September 1975.	R.C. Larson

IV. PROFESSIONAL ACTIVITIES

A. Publications

H.Z. AASHTIANI and T.L. MAGNANTI, "Implementing Primal-Dual Network Flow Algorithms," Working Paper OR 055-76, M.I.T. Operations Research Center, June 1976.

A.A. ASSAD, "Multicommodity Network Flows - A Survey," Working Paper OR 045-75, M.I.T. Operations Research Center, December 1975.

A.I. BARNETT, D.J. KLEITMAN and R.C. LARSON, "On Urban Homicide: A Statistical Analysis," Journal of Criminal Justice, Summer 1975.

A.I. BARNETT, "More on a Market Share Theorem," Journal of Marketing Research, February 1976.

A.I. BARNETT, "Control Policies for Transport Systems with Nonlinear Waiting Costs," Working Paper 850-76, M.I.T. Sloan School of Management, 1976.

A.I. BARNETT, "On Searching for Events of Limited Duration," Operations Research, May-June 1976.

G.R. BITRAN and A.C. HAX, "On the Design of Hierarchical Production Planning Systems," Technical Report No. 121, M.I.T. Operations Research Center, February 1976.

J.A. BLOOM, "A Mathematical Model of Fuel Distribution in New England," Technical Report No. 126, M.I.T. Operations Research Center, May 1976.

D.I. CANDEA, A.C. HAX and U.S. KARMARKAR, "Economic and Social Evaluation of Capital Investment Decisions - An Application," Technical Report No. 123, M.I.T. Operations Research Center, April 1976.

P.P. CHEN, "The Entity-Relationship Model," The Proceedings of the Conference on Very Large Data Bases, Framingham, Massachusetts, September 1975.

M.L. FISHER, W.D. NORTHUP and J.F. SHAPIRO, "Using Duality to Solve Discrete Optimization Problems: Theory and Computational Experience," Mathematical Programming Special Studies 3: Nondifferentiable Optimization, 56-94, November 1975.

H. GABBAY, "A Hierarchical Approach to Production Planning," Technical Report No. 120, M.I.T. Operations Research Center, December 1975.

N. GARTNER and J.D.C. LITTLE, "Generalized Combination Method for Area Traffic Control," Transportation Research Record 531, 58-69, 1975.

PROFESSIONAL ACTIVITIES: Publications

N.H. GARTNER, J.D.C. LITTLE and H. GABBAY, "Optimization of Traffic Signal Settings by Mixed-Integer Linear Programming, Part 1: The Network Coordination Problem," and "Part 2: The Network Synchronization Problem," Transportation Science, 9, 321-363, November 1975.

B.L. GOLDEN, "Vehicle Routing Problems: Formulations and Heuristic Solution Techniques," Technical Report No. 113, M.I.T. Operations Research Center, August 1975.

B.L. GOLDEN, "Shortest Path Algorithms: A Comparison," Working Paper OR 044-75, M.I.T. Operations Research Center, October 1975.

B.L. GOLDEN, "A Statistical Approach to the TSP," Working Paper OR 052-76, M.I.T. Operations Research Center, April 1976.

B.L. GOLDEN and T.L. MAGNANTI, "Deterministic Network Optimization: A Bibliography," Working Paper OR 054-76, M.I.T. Operations Research Center, June 1976.

B.L. GOLDEN, T.L. MAGNANTI and N.Q. NGUYEN, "Implementing Vehicle Routing Algorithms," Technical Report No. 115, M.I.T. Operations Research Center, September 1975.

J.J. GOLOVIN, "Hierarchical Integration of Planning and Control," Technical Report No. 116, M.I.T. Operations Research Center, September 1975.

C. GREENE and T.L. MAGNANTI, "Some Abstract Pivot Algorithms," SIAM Journal on Applied Mathematics, 29, 530-539, November 1975.

C. HAEHLING VON LANZENAUER and D.D. WRIGHT, "Developing an Optimal Repair-Replacement Strategy for Pallets," Working Paper OR 047-76, M.I.T. Operations Research Center, February 1976.

A.C. HAX, "The Design of Large Scale Logistics Systems: A Survey and an Approach," in Modern Trends in Logistics Research, W.H. Marlow (editor), M.I.T. Press, 1976.

A.C. HAX, J. GOLOVIN, M. BOSYJ and T. VICTOR, "COMS: A Computer-Based Operations Management System," Technical Report No. 125, M.I.T. Operations Research Center, June 1976.

A.C. HAX and K.M. WIIG, "The Use of Decision Analysis in Capital Investment Problems," Technical Report No. 118, M.I.T. Operations Research Center, October 1975. See also: Sloan Management Review, Vol. 17, No. 2, Winter 1976.

PROFESSIONAL ACTIVITIES: Publications

J.E. HUGUENIN and J.D.C. LITTLE, "Marketing Issues of 'Waste' Grown Aquatic Foods," Working Paper 837-76, M.I.T. Sloan School of Management, February 1976.

U.S. KARMARKAR, "Estimation of Fractiles for Order Point Determination," Technical Report No. 114, M.I.T. Operations Research Center, August 1975.

U.S. KARMARKAR, "Multilocation Distribution Systems," Technical Report No. 117, M.I.T. Operations Research Center, September 1975.

G.M. KAUFMAN, "Probabilistic Modelling of Oil and Gas Discovery," proceedings of conference on Energy: Mathematics and Models, Alta, Utah, July 1975.

G.M. KAUFMAN, "On Sums of Lognormal Random Variables," Working Paper 831-76, M.I.T. Sloan School of Management, 1976.

G.M. KAUFMAN, "Oil Supply Forecasting Using Disaggregated Pool Analysis," Working Paper MIT-EL-76-009WP, M.I.T. Energy Laboratory, May 1976.

R.C. LARSON, "Approximating the Performance of Urban Emergency Service Systems," Operations Research, 5, September-October 1975.

R.C. LARSON, "What Happened to Patrol Operations in Kansas City? A Review of the Kansas City Patrol Experiment," Journal of Criminal Justice, 3, 267-297, December 1975.

R.C. LARSON, "The Hypercube Queuing Model: An Introduction to Its Structure and Utility," Technical Report No. 20-75, Innovative Resource Planning Project, M.I.T. Laboratory of Architecture and Planning, December 1975.

R.C. LARSON and E.A. FRANCK, "Dispatching the Units of Emergency Service Systems Using Automatic Vehicle Location: A Computer Based Markov Hypercube Model," Technical Report No. 21-76, Innovative Resource Planning Project, M.I.T. Laboratory of Architecture and Planning, April 1976.

G.L. LILIEN and J.D.C. LITTLE, "The ADVISOR Project: Advertising Budgeting for Industrial Products," Working Paper 823-75, M.I.T. Sloan School of Management, November 1975.

G.L. LILIEN and J.D.C. LITTLE, "The ADVISOR Project: A Study of Industrial Marketing Budgets," Sloan Management Review, 17, 17-31, Spring 1976.

J.D.C. LITTLE, "BRANDAID: A Marketing-Mix Model, Part 1: Structure," and "Part 2: Implementation, Calibration and Case Study," Operations Research, 23, 628-673, July 1975.

PROFESSIONAL ACTIVITIES: Publications

T.L. MAGNANTI, "Nonlinear Programming and the Maximum Principle for Discrete Time Optimal Control Problems," Revue Francaise d'Automatique, Informatique et Recherche Operationelle, 3, 75-91, October 1975.

T.L. MAGNANTI, "Optimization for Sparse Systems," Technical Report No. 119, M.I.T. Operations Research Center, November 1975. See also: Sparse Matrix Computations, J.R. Bunch and D.J. Rose, editors, Academic Press, New York, New York, 1976.

R.E. MARSTEN, "The Use of the BOXSTEP Method in Discrete Optimization," Mathematical Programming Study 3, 127-144, November 1975.

R.E. MARSTEN and T.L. MORIN, "Parametric Integer Programming: The Right-Hand-Side Case," Working Paper 808-75, M.I.T. Sloan School of Management, September 1975. See also: Working Paper OR 050-76, M.I.T. Operations Research Center, March 1976.

R.E. MARSTEN and T.L. MORIN, "A Hybrid Approach to Discrete Mathematical Programming," Working Paper OR 051-76, M.I.T. Operations Research Center, March 1976. See also: Working Paper 838-76, M.I.T. Sloan School of Management, March 1976.

R.E. MARSTEN and T.L. MORIN, "An Algorithm for Nonlinear Knapsack Problems," Management Science, 22, 1147-1158, June 1976.

P.M. MORSE, "The Geometric and the Bradford Distributions, A Comparison," Working Paper OR 049-76, M.I.T. Operations Research Center, February 1976.

A.R. ODONI , "Expenditure and Employment Trends in Large City Police Departments: 1959-1973," Technical Report No. 16-75, Innovative Resource Planning Project, M.I.T. Laboratory of Architecture and Planning, July 1975.

A.R. ODONI and P. KIVESTU, "A Handbook for the Estimation of Airside Delays at Major Airports (Quick Approximation Method)," Report No. NASA CR-2644, June 1976.

A.R. ODONI and J.F. VITTEK, "Airport Quotas and Peak Hour Pricing: Theory and Practice," Report No. FAA-AVP-77-5, U.S. Department of Transportation, May 1976.

S. PARIENTE and A.C. HAX, "Computer Programs for Mathematical Programming Models in Production Planning," Technical Report No. 124, M.I.T. Operations Research Center, May 1976.

J.F. SHAPIRO, "OR Models for Energy Planning," Computers and Operations Research, 2, 145-152, December 1975.

PROFESSIONAL ACTIVITIES: Publications

J.F. SHAPIRO, "Steepest Ascent Decomposition Methods for Mathematical Programming/Economic Equilibrium Energy Planning Models," Working Paper OR 046-76, M.I.T. Operations Research Center, February 1976.

J.F. SHAPIRO, "Sensitivity Analysis in Integer Programming," Working Paper OR 048-76, M.I.T. Operations Research Center, February 1976.

J.F. SHAPIRO, "Multiple Criteria Public Investment Decision Making by Mixed Integer Programming," in Multiple Criteria Decision Making, edited by H. Thiriez and S. Zionts, Springer-Verlag, 170-182, 1976.

J.F. SHAPIRO, "A Survey of Applications of Integer and Combinatorial Programming in Logistics," Chapter 16 in Modern Trends in Logistics Research, edited by W.H. Marlow, M.I.T. Press, 1976.

R.E. WELSCH, "Stepwise Multiple Comparison Procedures," Working Paper 816-75, M.I.T. Sloan School of Management, 1975.

R.E. WELSCH, "Confidence Regions for Robust Regression," 1975 Proceedings of the ASA Statistical Computing Section, American Statistical Association, Washington, D.C., 1975.

R.E. WELSCH and E. KUH, "The Variances of Regression Coefficient Estimates Using Aggregate Data," Econometrica, 44, 353-363, March 1976.

R.T. WONG, "A Survey of Network Design Problems," Working Paper OR 053-76, M.I.T. Operations Research Center, May 1976.

PROFESSIONAL ACTIVITIES

B. Presentations

A.I. BARNETT, "Control Policies for Transport Systems with Nonlinear Waiting Costs," ORSA/TIMS National Meeting, Philadelphia, Pennsylvania, March-April 1976.

G.R. BITRAN and A.C. HAX, "On Design of Hierarchical Production Planning and Control Sytems," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

S.E. BODILY, "A Consensus Achieving Process for Group Preference," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

J.S. D'AVERSA and J.F. SHAPIRO, "An Analysis of Energy Equilibrium Models," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

A.W. DRAKE, "The Teaching of Statistics in Public Policy Schools," Joint Statistical Meeting, Atlanta, Georgia, 1975.

A.W. DRAKE, "Getting People to Give Blood: Ideologies, Practices and Issues," M.I.T. Technology Studies Seminar, Cambridge, Massachusetts, May 1976. Also, American Enterprise Conference on Blood Policy: Issues and Alternatives, Washington, D.C., June 1976.

J. FERREIRA, JR. and L. SLESIN, "Social Values and Public Policy: Implied Tradeoffs Between Accident Frequency and Severity," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

H. GABBAY, "Some Issues in Hierarchical Planning," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

N.H. GARTNER, "Multicriteria Area Traffic Control," ORSA/TIMS National Meeting, Philadelphia, Pennsylvania, March-April 1976.

B.L. GOLDEN, "Approaches to the Cutting Stock Problem," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

B.L. GOLDEN, "Shortest Path Algorithms: A Comparison," ORSA/TIMS National Meeting, Philadelphia, Pennsylvania, March-April 1976.

B.L. GOLDEN, T.L. MAGNANTI and H.Q. NGUYEN, "Implementing Vehicle Routing Algorithms," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

A.C. HAX, "Hierarchical Planning Systems," Summer Session Conference Series in Operations Research, University of Michigan, Ann Arbor, Michigan, August 1975.

PROFESSIONAL ACTIVITIES: Presentations

A.C. HAX, "The Use of Decision Analysis in Capital Investment Problems," Workshop on Decision Making with Multiple Conflicting Objectives, IIASA, Laxenburg, Austria, October 1975.

A.C. HAX, "Aggregate Production Planning," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

A.C. HAX, "Design and Implementation of Production Planning Systems," Workshop Series, Case Western Reserve University, Cleveland, Ohio, March 1976.

A.C. HAX, "Research Issues in Production Management," POM/ME Workshop, Harvard Business School, Boston, Massachusetts, March 1976.

R.C. LARSON, "Overview of Development and Use of the Hypercube Model for Planning in Urban Emergency Services," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

J.D.C. LITTLE, "Advertising Response Models," XXII International Meeting, TIMS, Kyoto, Japan, July 1975.

J.D.C. LITTLE, "Advertising Experimentation," American Marketing Association Conference, Rochester, New York, August 1975.

R.E. MARSTEN, "Parametric Integer Programming: The Right-Hand-Side Case," Workshop on Integer Programming, Bonn, West Germany, September 1975.

R.E. MARSTEN, "Recent Computational Advances in Mathematical Programming," lecture for the combined ORSA/TIMS chapters of Chicago, Illinois, February 1976.

R.E. MARSTEN, "Parametric Integer Programming," School of Industrial Engineering and Krannert Business School, Purdue University, Lafayette, Indiana, February 1976.

R.E. MARSTEN, "A Hybrid Approach to Discrete Mathematical Programming," ORSA/TIMS National Meeting, Philadelphia, Pennsylvania, March-April 1976.

R.E. MARSTEN and T.L. MORIN, "A Hybrid Dynamic Programming/Branch-and-Bound Approach to a Class of Sequencing Problems," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

A.R. ODONI and R. KIVESTU, "A Handbook of Daily Delays at Commercial Airports," ORSA/TIMS National Meeting, Las Vegas, Nevada, November 1975.

PROFESSIONAL ACTIVITIES: Presentations

J.F. SHAPIRO, "Sensitivity Analysis in Integer Programming," Workshop on Integer Programming, Bonn, West Germany, September 1975.

R.E. WELSCH, "Computer Implementation of Methods for Exploratory Data Analysis," American Statistical Association Short Course on Exploratory Data Analysis, August 1975.

R.E. WELSCH, "Robust Regression," M.I.T. Applied Mathematics Colloquium, Cambridge, Massachusetts, October 1975.

R.E. WELSCH, "Sensitivity Analysis and Statistics," Harvard Business School Managerial Economics Group, Boston, Massachusetts, January 1976.

R.E. WELSCH, "Sensitivity Analysis and Model Building," Carnegie-Mellon Statistics Colloquium, Pittsburgh, Pennsylvania, February 1976.

R.E. WELSCH, "Robust Estimation," National Bureau of Economic Research ROSEPACK Workshop, March 1976.

R.E. WELSCH, "Implementing a Least-Squares Algorithm," Argonne Symposium on Matrix Methods in Optimization," June 1976.

R.E. WELSCH, "Modular Mathematical Software for Iteratively Reweighted Least Squares," SIAM National Meeting, June 1976.

V. ADMINISTRATION

A. Personnel

Academic Staff

J.F. SHAPIRO, Acting Director
Professor of Operations Research and Management

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P.M. MORSE
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B. SIMEONE

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A.L. COOPER
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ADMINISTRATION

B. Research Support

The operations research work reported in Section II has been supported in various ways--some by the Center directly, some by other centers, laboratories and departments within M.I.T. and some by local industries or government agencies. Below are the individuals whose work was directly supported, in whole or in part, by O.R. Center contracts and grants during 1975-76.

A.A. ASSAD	D.P. ELLIOTT	T.L. MAGNANTI
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A.W. DRAKE	Z.A. LIVNE	R.E. WELSCH
		R.T. WONG

O.R. Center Contracts and Grants, July 1, 1975 - June 30, 1976

MASSACHUSETTS AUTOMOBILE RATING AND ACCIDENT PREVENTION BUREAU
"Evaluating the Consumer's Interest in Merit Rating Plans"

NATIONAL SCIENCE FOUNDATION
"Computer Science and Statistics: Ninth Annual Symposium on the Interface"

U.S. ARMY RESEARCH OFFICE
"Investigations in Methods of Operations Research"

U.S. DEPARTMENT OF TRANSPORTATION
"Transportation Network Analysis and Decomposition Techniques"

U.S. OFFICE OF NAVAL RESEARCH
"Multilevel Logistics Organization Models"

U.S. OFFICE OF NAVAL RESEARCH
"Computer Science and Statistics: Ninth Annual Symposium on the Interface"

U.S. PUBLIC HEALTH SERVICE
"Blood Donor Motivation and Recruitment"

INDEX TO AUTHORS OF REPORTS IN SECTION II